1989

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ABSTRACT

Six rotary grain cleaner models were tested for efficiency of removal of fine material from dry corn at various flow rates. Cleaners were equipped with soldered-wire screens having square openings averaging 5.3 mm (0.22 in.) on a side. Removal efficiency decreased (five models) or was constant (one model) with flow rate. All cleaners were progressively less efficient as the size of fine material was increased. Sizes were defined as foreign material [particles through 2.4-mm (6/64-in.) diameter], broken corn [particles through 4.8-mm (12/64-in.) diameter, but over 2.4-mm (6/64-in.) diameter], and large brokens [particles through 6.4-mm (16/64-in.) diameter, but over 4.8-mm (12/64-in.) diameter]. Flow density, defined as grain flow rate per unit rate of cleaning area exposure, explained a major share of the removal efficiency differences among cleaner models, at a given particle size.

INTRODUCTION

The presence of fine material in corn lowers its value and acceptance. Articles in newspapers and farm literature explain why grain-importing countries no longer want "dirty" U.S. corn (Erb, 1985). Fines make corn more difficult to dry and aerate (Grama et al., 1984). Corn with fines is increasingly prone to mold and insect invasion during storage (Hill et al., 1982).

Cleaning has been proposed as a means of enhancing corn quality and market acceptance. One analysis predicted that cleaning by use of a 4.8-mm (12/64-in.) diameter (or smaller), screen would yield a net profit to the operation (Bern and Hurburgh, 1988). A workshop group composed of persons from government, industry, commodity groups, and universities has recommended a change in U.S. corn grades that would identify foreign material as a separate factor from broken corn (NAEGA, 1986). Under this proposal, foreign material weight would be subtracted from shipment weight to compute saleable grain weight.

Article was submitted for publication in January 1989; reviewed and approved for publication by the Food and Process Engineering Div. of ASAE in June 1989.

Journal Paper J-13367 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 2790. Research supported by Farm Journal, Inc., and the Iowa Agriculture and Home Economics Experiment Station.

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Mention of product or trade names does not constitute endorsement by either the authors or Iowa State University.

Rotary Grain Cleaners for On-Farm Application

Pierce (1985) reported that the rotary-type cleaner probably is most common for on-farm application. Rotary grain cleaners separate grain into size fractions by moving it through a trommel (revolving cylindrical screen with axis slightly inclined). As the trommel rotates, material cascades over its surface, and fine material passes through the screen. Material not passing through moves out the end of the trommel. Some cleaners employ a second trommel with larger openings for scalping (removal of material larger than the grain being cleaned). The second trommel may be concentric with or an extension of the first. Pierce reported that models are available with maximum manufacturer-rated capacities from 12.7 to 89.1 t/h (500 to 3500 bu/h)*.

Rotary Cleaner Performance

Rotary cleaner performance can be assessed by throughput and removal efficiency. Throughput increases with increased rotational speed. However, at increased speeds, blinding (screen plugging) can occur if material is crowded through the screen. Brown et al. (1950) stated that the best operating speed is between 33% and 45% of critical speed. Critical speed is the minimum rotational speed at which cascading ceases and material remains in constant screen contact, held there by centrifugal force. Critical speed is a function of trommel diameter

$$N = 1337/\sqrt{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

where

N = critical speed, r/min,
D = trommel diameter, mm.

Manufacturers often state that throughput may be reduced by increasing grain moisture, by decreasing trommel slope, by increasing fines content, and by certain grain types (Pierce, 1985).

Sucher and Pfost (1964) tested a trommel for removal of rodent pellets from corn. They found that, at speeds below critical speed, removal efficiency decreased as throughput increased but increased with increasing speeds. The speed effect was most pronounced at high throughput rates. The greatest removal efficiencies occurred at the highest speed tested, — 87% of critical speed.

Cleaner Efficiency

Two indexes are normally used to describe cleaner performance, efficiency, and percentage points removal

* Assumes 1 bu = 56 lb corn = 25.45 kg.

(Quinn, 1987). If the following symbols are defined

W_o, W_f = initial (uncleaned) and final (cleaned) weights,

w_o, w_f = initial and final weights of cleanings; of the size to be removed, contained in W_o, W_f,

p_o, p_f = initial and final percentages of cleanings then the efficiency, E, as a decimal is

$$E = \frac{w_o - w_f}{w_o} = \frac{p_o W_o - p_f W_f}{p_o W_o} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Because

$$W_f = W_o - \left[\frac{p_o W_o}{100} - \frac{p_f W_f}{100} \right] \quad \ldots\ldots\ldots\ldots\ldots [3]$$

then

$$E = 1.0 - \frac{p_f(100 - p_o)}{p_o(100 + p_f)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots [4]$$

If p_o and p_f are small and nearly equal, then $W_f \sim W_o$ and $E \sim 1.0 - p_f/p_o$, an expression often used by cleaner manufacturers.

The index percentage points removed is used because the objective in most grain cleaning operations is to reach some grade limit but no cleaner. Subtracting target percentage from initial percentage gives a quick and practical measure of the quantity to be removed.

Objectives

1. Determine removal efficiency of six rotary screen cleaners for removing fine material of various sizes from corn.
2. Identify design or operation parameters that would predict rotary cleaner efficiency, regardless of brand.

MATERIALS AND METHODS

Equipment

Important specifications of the cleaners are listed in Table 1. Inside openings of the soldered wire-mesh square screens was determined from 10 micrometer-caliper measurements per cleaner. Only the openings of the fines removal area were measured. Several of the cleaners were also equipped with an additional soldered-wire screen with large openings for removal of material larger than corn. Cleaners 1, 3, 4, 5, and 7 had statistically equivalent wire openings. Obviously, the larger the opening, the more material will pass. All the cleaners had significantly larger screen openings than would be required to remove only BCFM. Whether this is a detriment would depend on whether the grain is being cleaned to make grade or for storage management purposes.

Measurement of Broken Corn and Foreign Material

BCFM is defined as all material that will pass through a 4.8-mm (12/64-in.) round-hole screen plus any nongrain material remaining atop this screen. As of 1 May 1988, separate definitions were also made for broken corn (BC) and foreign material (FM). BC is material passing through the 4.8-mm (12/64-in.) screen but over a 2.4-mm (6/64-in.) round-hole screen. FM is material passing through the 2.4-mm (6/64-in.) screen plus the nongrain material atop the 4.8-mm (12/64-in.) screen. BCFM is still the factor used to determine Official grade of corn, but the percentages of BC and FM are listed separately on Official certificates for informational purposes.

Removal Efficiency

Removal efficiency was determined from samples collected after cleaning and from an analysis of the cleanings removed. We measured BC, FM, and BCFM in samples with a double-screen in a Carter Dockage Tester. This is the same procedure as used in Official USDA inspections. After removing BC and FM, we also cleaned samples over a 6.4-mm (16/64-in.) screen, which removed large broken pieces and shriveled kernels too large to be classed as BC but still not sound kernels. This

TABLE 1. Specifications of the cleaners

		Rated Capacity*		Cleaning area (ft^2): Rated*		Cleaning area (ft^2): Measured (fines removal only)		Screen opening: Inside distance†		Screen opening: Range†	
ID No.	Brand and Model	t/h	bu/h	m^2	ft^2	m^2	ft^2	mm	in	mm	in
1	Farm Fans C6140	30.5	1200	2.69	29	2.32	25	5.69§	0.224§	0.254	0.010
2	Feterl 85	50.9	2000	2.60	28	2.60	28	5.51	0.217	0.508	0.020
3	Gilmore Tatge 1580	45.8	1800	7.90	85	5.02	54	5.69§	0.224§	0.203	0.008
4‡	Sioux Steel 42	48.4	1900	7.15	77	5.95	64	5.66§	0.223§	0.127	0.005
5	Sukup 48	61.1	2400	8.18	88	6.13	66	5.72§	0.225§	0.406	0.016
6	David Mfg. Co. 54	76.4	3000	9.20	99	8.55	92	5.89	0.232	0.559	0.022
7	NECO 51A	63.6	2500	6.69	72	7.06	76	5.74§	0.226§	0.584	0.023

* From manufacturer data, capacities for dry corn.
† Based on 10 measurements per cleaner (All had soldered wire-mesh screens)
‡ Cleaning performance not tested because of electric motor problem
§ Statistically equivalent (P = 0.05)

material will be referred to as large brokens (LB). LB will not detract from grade but will affect drying and storage. The grain we used had virtually no large FM (material remaining atop the 4.8-mm (12/64-in.) screen. Therefore, we did not handpick samples or the cleanings. FM data is only screened FM.

Procedures

The cleaners, all furnished by respective manufacturers, were set up in a large temporary storage bunker at the West Central Co-op Elevator, Jordan, IA. The elevator supplied the corn from its truck loadout bin.

Cleaners were tested at 50%, 100%, and 120% (if possible) of rated throughput by using dry corn averaging 3.1% BCFM as it entered the cleaners. Duplicate tests were made for each flow rate. One test consisted of cleaning for 2.0 min at the preset flow rate. Flow rates were established by calibrating the output of the scale wagon used to transport the uncleaned grain. The scale wagon weighed to ±4.5 kg (10 lbs). Flow rate from its output auger was calibrated against rotational speed of its gasoline engine. The auger calibration curve was used to set the approximate flow rate; each test was timed, and the exact flow rate was then calculated. Corn was used only once. Cleaned corn was directed into a portable auger, then to a wagon for return to the elevator.

Cleaners 1 and 2 were tested at all three flow rates. Cleaners 3, 5, 6, and 7 were tested at 50% and 100% only because the scale wagon and the clean-grain auger would handle a maximum of 63.9 t/h (2500 bu/h). Cleaner 4 had a defective electric motor and was not tested.

Samples were taken with a sampling pan at the entrance to the cleaner feed auger and at the cleaner exit. Cleaners 1 and 3 did not have a feed auger; corn was spouted directly from the wagon into the cleaner drum.

Cleanings from each test were collected and weighed. Cleaners 1 and 2 had no method for gathering cleanings, so we collected them on a canvas placed under the trommel. With the canvas, there was more chance for stray kernels to be included in the cleanings and more chance to lose cleanings. The other cleaners had provision to collect cleanings.

Both the samples and the cleanings were separated into BC, FM, and LB. There was material larger than LB, including some whole kernels, in the cleanings.

Data Analysis

Removal efficiency can be calculated for any range of particle sizes; for the cleaners, the important efficiencies were for FM, BC, BCFM, pooled LB, larger than LB, and all material larger than BCFM.

Removal efficiency was calculated by comparing the amount of cleanings, by size, to the respective concentrations in the inlet grain. We had two methods of determining the fines level of the uncleaned grain—1) from the inlet sample, and 2) by calculation from the cleanings weight and the outlet sample. The two methods did not match. We chose the latter method because the inlet sample was difficult to take and appeared to be overly concentrated in fines. Removal efficiency, E_i, for any size i then becomes

$$E_i = \frac{p_{ci} W_c}{p_{oi} W_o} \cdot 100 \quad \ldots\ldots [5]$$

where

p_{oi} = percentage of size i in uncleaned grain,
p_{ci} = percentage of size i in cleanings,
W_c = total weight of cleanings,
W_o = total weight of uncleaned grain.

RESULTS AND DISCUSSION

Detailed data from the 28 tests are shown in Table 2. The inlet concentrations were calculated from the outlet sample data and the analyses of the cleanings. We achieved the target flow rates of 50%, 100%, and 120% capacity reasonably well and with good repeatability between duplicate tests. Every cleaner except number 1 showed a consistent decline in removal efficiency as flow rate increased. Likewise, particles closer to the screen opening size were removed at lower efficiency, BC less than FM, and LB less than BC. Also, all the cleaners removed or splattered a small amount of corn, approximately 0.1-0.2% of the inlet weight. From a marketing viewpoint, both LB and whole corn are equally saleable. Therefore, the last column of Table 2 shows the total loss of saleable material, LB plus whole corn.

As shown in Figs. 1-4, the cleaners differed in removal efficiency. The lines on Figs. 1-4 were obtained from regression of efficiency against flow rate, by model. These graphs compare changes in cleaning efficiency among cleaners for the four classes of particles. LB particles, while still broken corn, are larger than BCFM and thus would not be discounted by the market. Both the percentage removal efficiency and the decline in removal efficiency with increasing flow rate were not the same for all cleaners. The differences among cleaners (in average efficiencies and slopes, with respect to flowrate) were more obvious for the larger particles (BC and LB), closer to the screen opening size. A cleaner with an overrated capacity would have its data consistently lower and to the left of a more conservatively rated cleaner.

Whether a lower removal efficiency is undesirable depends on the operator's objectives. Meeting grade specifications will not require complete cleaning unless standards change to begin FM discounting at zero or nearly zero percent. On the other hand, significant storage cost savings can be had from cleaning even No. 2 corn before binning (Bern and Hurburgh, 1988).

The ratio of grain weight to cleaning area seemed to be a critical parameter in determining performance. Accordingly, the variable, flow density F, was defined as

$$F = \frac{16.67Q}{NA} \quad \ldots\ldots [6]$$

where

F = flow density, kg/m^2,
Q = flowrate, kg/h,
N = rotational speed, r/min,
A = cleaning area, m^2

or

$$F = \frac{Q}{60\,NA} \quad \ldots\ldots [7]$$

TABLE 2. Cleaning data for the six rotary screen cleaners

				FM		BC		BCFM		LB		Loss of Saleable Weight	
Cleaner	t/h	Flowrate (bu/hr)	% Capacity	Inlet (%)	Efficiency (%)	Inlet (%)	Efficiency (%)	Inlet (%)	Efficiency (%)	Inlet (%)	Efficiency (%)	Corn Only (%)	Corn + LB (%)
1	21.81	857	71	0.8%	77.7%	2.5%	47.4%	3.4%	54.9%	2.9%	14.2%	0.2%	0.6%
	22.91	900	75	0.3%	61.9%	1.3%	24.4%	1.6%	31.6%	2.1%	5.6%	0.2%	0.3%
	23.31	916	76	0.4%	66.9%	2.0%	25.2%	2.4%	32.8%	2.8%	5.0%	0.2%	0.3%
	31.63	1243	104	0.6%	77.1%	2.3%	49.6%	2.9%	55.0%	2.8%	12.5%	0.2%	0.6%
	32.98	1296	108	1.1%	63.7%	2.4%	39.4%	3.5%	46.9%	2.7%	12.0%	0.2%	0.5%
	33.11	1301	108	0.8%	70.0%	2.2%	37.6%	3.1%	46.4%	2.5%	10.8%	0.1%	0.4%
2	26.03	1023	52	1.2%	95.8%	2.3%	71.8%	3.5%	80.0%	2.6%	34.9%	0.3%	1.2%
	29.04	1141	57	1.4%	93.7%	2.3%	67.3%	3.7%	77.3%	2.6%	32.5%	0.2%	1.1%
	54.67	2148	107	0.9%	72.8%	2.2%	41.8%	3.1%	50.9%	2.7%	17.3%	0.2%	0.7%
	55.76	2191	110	1.1%	68.9%	2.2%	40.3%	3.3%	49.9%	2.7%	17.0%	0.1%	0.6%
	64.06	2517	126	1.1%	68.7%	2.2%	35.6%	3.4%	46.6%	2.7%	14.9%	0.2%	0.6%
	65.02	2555	128	0.9%	64.1%	2.5%	29.8%	3.4%	39.0%	2.9%	14.6%	0.1%	0.6%
3*	28.35	1114	62	0.5%	91.8%	2.5%	66.7%	3.1%	71.2%	2.9%	35.7%	0.1%	1.1%
	30.41	1195	66	0.4%	81.1%	2.1%	55.8%	2.5%	60.2%	2.8%	29.3%	0.1%	0.9%
	41.72	1639	91	1.6%	55.6%	2.8%	34.6%	4.4%	42.1%	2.8%	19.2%	0.1%	0.7%
	51.94	2041	113	1.7%	28.7%	3.1%	27.6%	4.8%	28.0%	2.7%	15.7%	0.1%	0.5%
5†	31.91	1254	52	0.7%	94.9%	2.5%	69.5%	3.2%	75.1%	3.1%	28.8%	0.1%	1.0%
	32.32	1270	53	0.6%	93.8%	2.4%	74.0%	3.0%	77.7%	2.5%	32.5%	0.1%	0.9%
	51.54	2025	84	0.8%	89.3%	2.4%	57.4%	3.2%	65.7%	2.7%	23.8%	0.1%	0.8%
	58.61	2303	96	0.8%	80.2%	2.6%	50.0%	3.4%	57.3%	3.0%	21.7%	0.1%	0.7%
6‡	33.54	1318	44	0.9%	99.5%	2.3%	88.8%	3.1%	91.8%	2.7%	53.5%	0.3%	1.7%
	35.45	1393	46	0.3%	97.9%	1.7%	87.4%	2.1%	89.0%	2.9%	44.7%	0.2%	1.5%
	63.96	2513	84	0.7%	82.4%	2.0%	45.9%	2.7%	55.0%	2.6%	22.1%	0.2%	0.8%
	64.62	2539	85	0.6%	84.6%	1.9%	51.9%	2.5%	59.2%	2.7%	23.8%	0.1%	0.7%
7‡	32.45	1275	51	0.4%	88.5%	2.2%	73.1%	2.6%	75.7%	2.7%	30.5%	0.1%	0.9%
	32.73	1286	51	0.6%	91.7%	2.1%	77.0%	2.7%	80.3%	2.8%	29.1%	0.2%	1.0%
	63.52	2496	100	0.7%	66.8%	2.5%	49.0%	3.2%	52.9%	2.7%	25.1%	0.1%	0.8%
	64.49	2534	101	0.9%	56.6%	3.1%	44.8%	4.0%	47.5%	3.1%	23.6%	0.1%	0.8%
Averages				0.8%		2.3%		3.1%		2.7%		0.2%	

* Cleaning drum would not handle 120% of rated capacity
† Feed auger to cleaner would not handle 120% of rated capacity
‡ Flowrate limited by output of scale wagon

where
F = flow density, bu/ft^2,
Q = flow rate, bu/h,
N = rotational speed, r/min,
A = cleaning area, ft^2.

A plot of removal efficiency, E, vs. flow density, F, (all cleaners) for the BCFM size is shown in Fig. 5. Data points lined up remarkably well despite the differences in cleaner design and flow rate. Similar patterns held for the FM, BC, and LB sizes. The following equations (in SI units) were derived to predict E in terms of flow density.

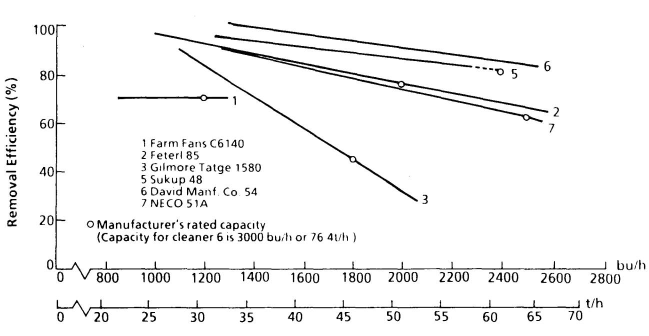

Fig. 1—Efficiency of six rotary cleaners in removing foreign material (FM) from corn. [FM = material smaller than 2.4-mm (6/64-in.) diameter.]

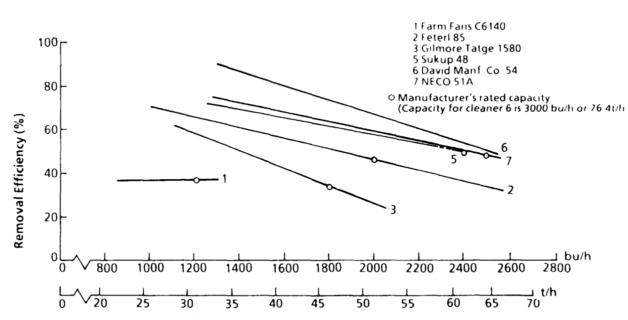

Fig. 2—Efficiency of six rotary cleaners in removing broken corn (BC) from corn. [BC = material smaller than 4.8-mm (12/64-in.) diameter, but larger than 2.4-mm (6/64-in.) diameter.]

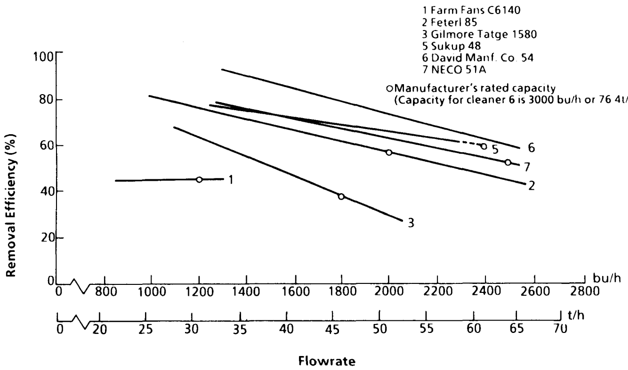

Fig. 3—Efficiency of six rotary cleaners in removing broken corn-foreign material (BCFM) from corn. [BCFM = material smaller than 4.8-mm (12/64-in.) diameter.]

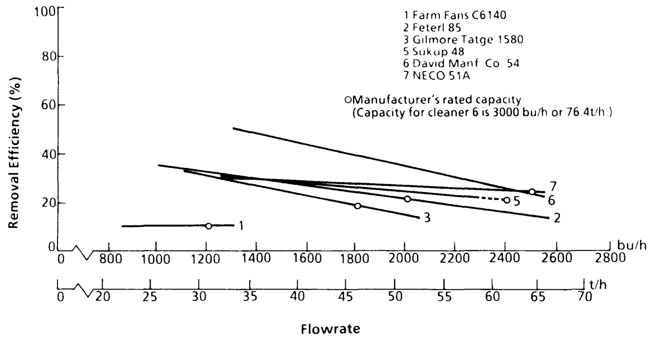

Fig. 4—Efficiency of six rotary cleaners in removing large broken (LB) corn [LB = material smaller than 6.4-mm (16/64-in.) diameter, but larger than 4.8-mm (12/64-in.) diameter.]

$$\text{FM:}\quad E = -6.72F + 114.6 \qquad R^2 = 0.48 \qquad s = 12.0 \quad \text{[8]}$$

$$\text{BC:}\quad E = -8.66F + 100.4 \qquad R^2 = 0.62 \qquad s = 11.6 \quad \text{[9]}$$

$$\text{BCFM:}\quad E = -8.04F + 103.2 \qquad R^2 = 0.60 \qquad s = 11.2 \quad \text{[10]}$$

$$\text{LB:}\quad E = -4.86F + 50.2 \qquad R^2 = 0.53 \qquad s = 7.9 \quad \text{[11]}$$

To use these equations with flow density in conventional units, multiply F in bu/ft^2 by 273.94 to obtain F in kg/m^2.

Equations [8] through [11] would not apply directly if different sizes of screens were installed, but in all probability, removal efficiency would still be some function of F. In any event, an increase in flow density

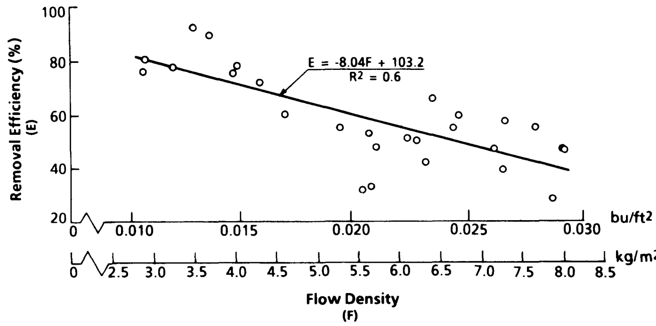

Fig. 5—BCFM removal efficiency vs. flow density for rotary cleaners.

will unambiguously decrease efficiency of rotary trommel cleaners. The flow density statistic seems to be a useful parameter for evaluating cleaner performance.

CONCLUSIONS

1. Removal efficiency for all sizes of particles generally declined as flow rate increased.
2. Removal efficiency was lower for particle sizes closer to the screen opening size.
3. There were sizable differences in removal efficiency among the cleaner models. At rated capacity, the ranges in removal efficiency amoung cleaners were 42-80%, 37-58%, and 10-24% for FM, BC, BCFM, and LB, respectively.
4. The cleaners removed 0.5-1.5% by weight of material larger than BCFM, with 0.2% being whole corn. The remainder was large brokens (LB).
5. Flow density, defined as grain flow rate per unit cleaning area exposure rate, explained about 60% of the differences in removal efficiency amoung cleaner models.

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